The 1962 Survey of Noise and Loss on Toll Connections

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The 1962 sample survey of message circuit noise and loss on Bell System toll connections is described and discussed in this article. The results are presented in terms of the distribution of noise levels on toll calls as established in the present system, the distribution of end-office to end-office losses on these calls, and the distribution of airline distances between end-offices. It is shown that the noise distribution referred to the subscriber's set has a mean of 19.7 dbrne with a standard deviation of 7.8 db, that the mean of the distribution of end-office to end-office losses is 7.7 db with a standard deviation of 3.0 db, and that 50 per cent of all toll calls are shorter than 30 miles, while only 10 per cent span a distance of more than 250 miles. The noise level versus distance and loss versus distance relationships are investigated and analyzed. The noise level is found to increase by 2.2 db for each doubling of the airline distance between end-offices, while the loss shows an increase of 0.6 db for each doubling of the distance. Finally, present performance of the Bell System toll plant is evaluated in terms of noise and volume grade-of-service estimates.

I. INTRODUCTION

Most transmission engineering studies require some knowledge about the noise and loss performance of the telephone plant. When transmission objectives are being reviewed and new ones are to be set, such knowledge is of particular importance. Because of the significance of decisions in this area, it is necessary that the data used be representative and give an accurate systemwide picture of the performance. Recognizing these needs in the current work of setting new message circuit noise objectives, a nationwide sample survey of noise and loss on toll connections in the Bell System toll network has been undertaken. It is the purpose of this article to describe the survey and discuss its results. The application of the findings of the survey to the setting of new over-

all message circuit noise objectives is treated in an accompanying article.[1]

II. DEFINITION OF POPULATION

As in any sample survey, it is important that a precise definition be given of the population, in order that the extent and limitation of the survey results be known.

The population was defined to consist of all toll calls made during the busy hour of an ordinary business day and originating from Bell System central office buildings within Continental U.S.A. However, only those central office buildings were included that were in service at the beginning of 1960, while all Bell System and independent company central offices in Continental U.S.A. were included as terminating points for the toll calls. The busy hour was defined as the "official" busy hour of the toll office on which the originating central office homes. It was not considered practical to study the variation with time of the noise distribution on toll calls, and therefore the arbitrariness introduced by not specifying one or more particular "ordinary business days" was accepted.

All calls terminating within Continental U.S.A. were considered to be toll calls if they satisfied the following two criteria: (*i*) the customer was detail billed for the call; i.e. an operator ticket was issued or the call was recorded by automatic message accounting (AMA) equipment, and (*ii*) the originating and terminating central offices did not home on the same toll office. The latter criterion was introduced because, in areas with extended area service (EAS), the customers are in general not detail billed for those short-haul calls where originating and terminating central offices home on the same toll office. However, in areas where EAS has not been introduced, the opposite is in general true. This accounts for large deviations in the apparent toll calling patterns between central offices. Since these deviations are only artificial, and since they contribute toward a decrease in sampling precision, criterion (*ii*) above was introduced in order to make such deviations less pronounced.

III. SAMPLING PLAN AND SAMPLE SIZE

The sample was selected in two stages in the following way:*

From a listing of the 7878 Bell System central office buildings in

* Detailed discussions of the sampling plan used and of methods for determining the sample size and selecting the sample are found in standard works on the subject of sample surveys. See Refs. 2 and 3.

service at the beginning of 1960, 17 were selected at random. The probability of selecting any one office was made proportional to an estimate of size, where the size of the office is defined as the number of outgoing toll calls in the busy hour of an ordinary business day. The number of lines per office served as an estimate of this size, and the assumption was made that these two numbers were approximately proportional. Randomness in the selection was assured by the use of tables of random numbers. After these offices had been chosen, information was acquired from each of them about its outgoing toll traffic. This information had the form of lists of all outgoing detail billed toll calls during the busy hour of one ordinary business day. It was, however, estimated that in some offices the total outgoing toll traffic would be less than the sample size. For these cases the lists contained the outgoing toll traffic during the busy hour of several consecutive business days. The data for the lists were obtained from operator toll tickets and AMA printouts. The main information given for each call was the terminating central office. By the use of information in the Long Lines Dept. dial routing pamphlet, it was then possible to exclude from these lists all calls that terminated in a central office that homed on the same toll office as the originating central office. Furthermore, information in the Long Lines Dept. distance dialing reference guide was used to exclude all calls that did not terminate inside Continental U.S.A.

To test the whole procedure for the survey, a pilot survey was performed at Dover, N. J., in the spring of 1962. Among other results, this survey showed the ratio of the number of long-haul calls to the number of short-haul calls to be quite low. However, in order for us to be able to perform an analysis of noise level versus distance, it was necessary that the sample contain a reasonably large number of both short-haul and long-haul calls. In view of this, the findings at Dover indicated that the sample size would have to be made very large in order for the sample to contain a reasonably large number of long-haul calls, and this would imply making an unnecessarily large number of measurements on short-haul calls. To solve this problem, it was decided to perform two separate surveys, one on toll calls terminating inside the originating numbering plan area (NPA), and the other on calls terminating outside the originating NPA. These two surveys will be referred to as subsurveys of the connection survey.

All entries on the lists of outgoing toll calls were therefore referred to one of the two categories defined above. After this had been done, the total number of calls to be included in the sample for each subsurvey and each central office was determined. Finally, this number of calls was selected from the corresponding list by the use of random number tables.

In this selection, all entries on a list had the same probability of being included in the sample.

Table I lists the 17 central offices included in the sample as well as the corresponding number of inside-NPA and outside-NPA calls. The table shows that the sample contained a total of 514 inside-NPA calls and 727 outside-NPA calls. For each of the 17 central offices, the sample size was determined in such a fashion that the resulting sample is self-weighting. This means that all measurements taken carry equal weight, and it leads to convenient and straightforward methods of data analysis.

The sample sizes were determined from estimates of variability of noise level readings within and between central offices, combined with the precision criterion that the mean of the noise distribution be stated within ±1 db at the 90 per cent confidence level.

IV. METHOD OF MEASUREMENT

The measurement phase of the survey consisted of setting up the toll connections selected in the sample and measuring the noise and loss at the originating end; see Fig 1. The connections were set up so as to duplicate as closely as possible the conditions prevailing at the time the original call was made. All of the original calls were made during the busy hour of an ordinary business day. The probabilities of alternate

Table I — Connection Survey Sample Sizes

Central Office Location	Sample Size	
	Inside NPA	Outside NPA
Boston, Mass.	72	126
Brooksville, Fla.	24	88
Cheshire, Conn.	33	20
Dallas, Tex.	2	23
Detroit, Mich.	9	28
El Paso, Tex.	0	8
Fairfield, Conn.	40	50
Fort Lauderdale, Fla.	21	13
Hyattsville, Md.	3	8
Keyport, N. J.	100	22
Kingston, Pa.	17	23
Knoxville, Tenn.	11	21
Niagara Falls, N. Y.	77	30
Queens, N. Y.	0	137
Richmond, Va.	11	15
Riverside, N. J.	61	96
Selma, Cal.	33	19
Total sample size:	514	727

Fig. 1 — Connection survey measurements in a Boston central office.

routing and of high loading of the transmission facilities are then high. To keep these probabilities at the same levels, all measurements were performed during the busy period of ordinary business days.

The conditions at the time the original call was set up differed from those during our measurements in one respect: all measurements were made from the originating central office and they all terminated in the distant central office; in other words, the loops were excluded from consideration. This was done deliberately in order to isolate the transmission characteristics of the toll plant from those of the loop plant. In addition, any other procedure would have been very impractical and time-consuming, since it would involve subscribers at least at one end of the connection. In considering a toll connection from subscriber to subscriber, the influence of the loop plant must be taken into account; its performance is reported on in the accompanying article.[1]

For each sample call two measurements were made. In the first one, the near-end noise level was recorded on a toll connection terminated in the distant central office. The distant termination was made either in the quiet or balanced termination of the central office, or in the "hold" circuit of a telephone set in that office, or by a telephone set itself — in the latter case with the transmitter covered so that room noise was ex-

cluded from the connection. The use of the quiet termination of the distant office was avoided in all cases where "on-hook" supervision of that termination was known or could be suspected, since this condition results in the in-band signal on some types of carrier being left on. Such a tone would tend to give an erroneously high noise reading on the connection. As can be seen by this example, care was exercised to ensure that all noise measurements gave the noise level that would occur in the silent intervals between speech on actual telephone connections.* Termination in a telephone set, with the transmitter covered, was used only in those cases where no telephone set with "off-hook" supervision in the distant central office was equipped with a "hold" feature. In these cases, monitoring at the receiving end ensured that room noise was effectively kept out of the connection.

The second measurement for each call in the sample was made to record the end-office to end-office loss. For practical reasons a standard-level tone could not be supplied from the far end on the noise measurement calls. Therefore a new connection was established, terminating in the 1000-cycle milliwatt supply of the distant office. In this way, it is entirely possible that the two calls were routed differently. No effort was made to find out what route was used in any particular case. Therefore the route length of the connections is not known. However, distance is an important parameter. The airline distance between the end-offices was therefore associated with each measured connection.

Both types of connections mentioned above were established from an ordinary telephone set connected to a "zero" loop in the originating central office. This set was located in the same building as the central office equipment.

After a particular connection had been established, the set was switched out of the circuit and replaced by a 900-ohm resistor across which a 3A noise measuring set[4] was connected in the bridging position. The time average during 10–30 seconds of the level indicated by the 3A set was taken as the noise level reading of the circuit. The noise measuring set was always used with C-message weighting, and hence the measured levels are expressed in dbrnc. Since the C-message weighting introduces no loss at 1000 cycles, it was used also in the measurement of end-office to end-office loss.

Routing of outgoing toll calls could in general be expected to be different for operator-handled versus direct-dialed (DDD) calls. This

* When compandors are present in a connection, the noise level during speech is higher than in the silent intervals. The subjective rating of the noise is therefore poorer than that based on the measured noise level. This compandor effect will be ignored.

fact was taken into account in the natural way; connections were set up by operators or direct dialed depending on whether the original calls were operator-handled or AMA-recorded.

All of the terminating central offices were not equipped with milliwatt supplies or balanced terminations, nor were all of them attended. This meant that some measurements could not be made with distant terminations as given by the calls in the sample. The method used to treat these cases was to make measurements on a toll connection terminated in a central office geographically close to the desired one. The errors introduced by this procedure were judged to be negligibly small for long-haul calls and small enough to be disregarded even for short-haul calls. For calls terminating inside originating NPA, 1.9 per cent of the noise measurements and 8.8 per cent of the loss measurements had to be made with a substituted terminating central office. For outside-NPA calls, the corresponding figures are 1.1 per cent and 3.9 per cent.

V. CONNECTION SURVEY RESULTS

All data were punched on IBM cards, and most of the analysis reported here was made on the IBM 7090 digital computer at the Murray Hill, N. J., location of Bell Telephone Laboratories. One card was punched for each call in the sample; each card gives the originating and terminating central offices of the corresponding toll connection, the measured noise level, the measured end-office to end-office loss, and the airline distance between the central offices. The latter were computed by the use of geographical coordinates given in the Long Lines Dept. distance dialing reference guide.

In the discussion to follow, a set of measurements called the "pooled" data will be referred to several times. In particular, it will be used whenever the performance of all toll calls is discussed. This set of data consists of 998 toll calls, of which 514 are inside-NPA and 484 outside-NPA calls. In this way, all inside-NPA calls and part of the 727 outside-NPA calls are included; the percentage of outside-NPA calls included was chosen to make the pooled data representative of all toll calls. This percentage reflects the fact that 52 per cent of all toll calls terminate inside and 48 per cent outside the originating NPA.

5.1 *Noise*

Evaluation of grade of service[1] cannot be made directly from the survey noise distributions. The reason is that subscribers' reactions are given in terms of opinion curves for noise measured across their subset,

while all measurements in the survey were made at the end of a "zero" loop. The conversion from this point of measurement to the subscriber set is, however, quite simple. The equalizing properties of tbe 500 set imply that the combined response of loop and receiver is essentially constant for loop lengths up to 15,000 feet. A recent survey of loop characteristics has shown this to account for about 83 per cent of all Bell System loops.[5] For these loops, then, an increased loop loss is compensated for by a bigber sensitivity of the receiver. For the opinion curves to be applicable, the connection noise should therefore be transformed to the end of a loop equipped with a subset having the same sensitivity as the subsets used in the subjective tests that established the opinion curves. Tbe sensitivity is determined by the dc current, which was 55 ma in the above-mentioned tests. A regression analysis of loop loss vs dc current, using data from recent loop surveys,[1] showed the average loss of a 55-ma loop terminated in a 500 set to be 5 db. Therefore the conversion to the subset is made by subtracting 5 db from the noise levels measured in the connection survey, and after this

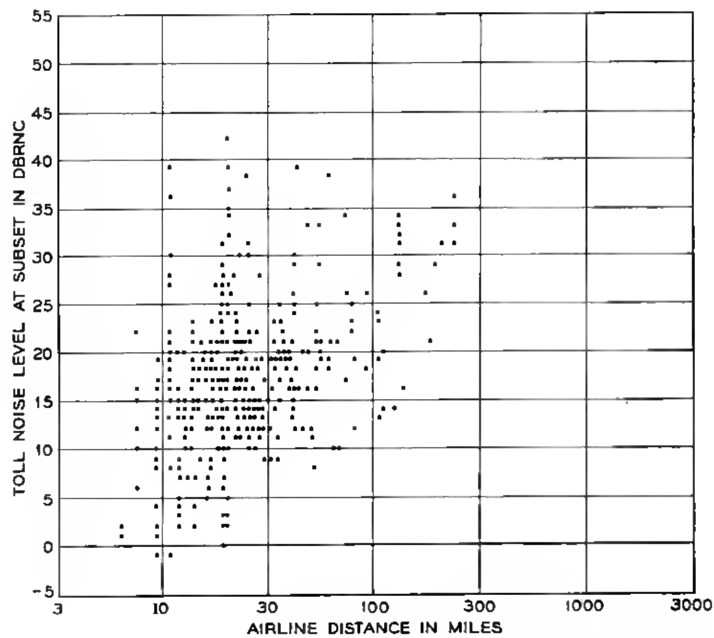

Fig. 2 — Scatter diagram of noise level vs distance: toll calls terminating inside NPA.

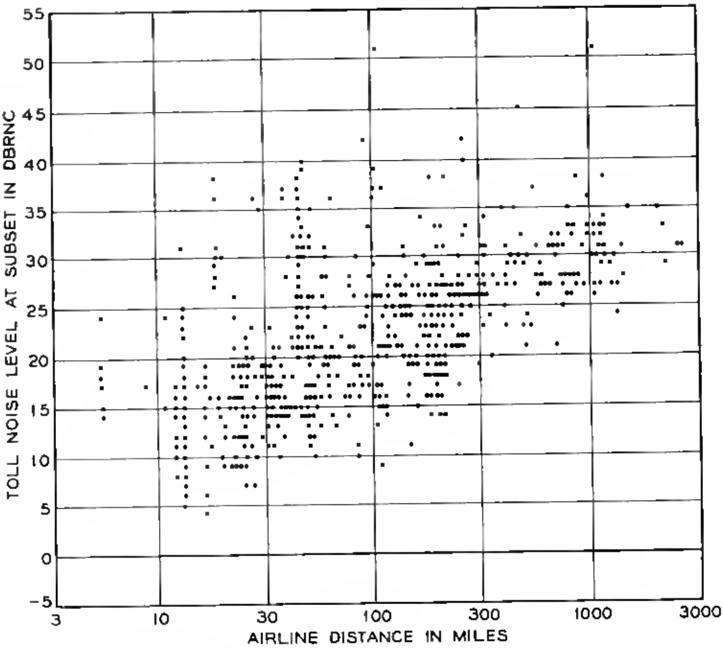

Fig. 3 — Scatter diagram of noise level vs distance: toll calls terminating outside NPA.

conversion the opinion curves can be applied directly to evaluate noise grade of service.

For loops longer than about 15,000 feet the combined loss of loop and receiver is larger than for the shorter loops. The received noise levels are therefore lower and the percentage of calls classified good or better is higher. However, the received volumes are also consistently lower, and therefore it would be incorrect to regard the service provided to these subscribers as superior to the service provided to subscribers on short loops. These arguments justify the use of one loop loss figure for all loops in the conversion of noise levels to the subscriber set. In the discussion to follow, all noise levels are referred to the subset.

The relation between noise level and distance is shown in Figs. 2 and 3, which are scatter diagrams wherein the abscissa gives the airline distance in miles and the ordinate gives the measured noise level referred to the subset. From these figures we observe that the noise levels increase with distance and that the variability of the noise levels decreases with distance. The scatter diagrams cannot be used directly

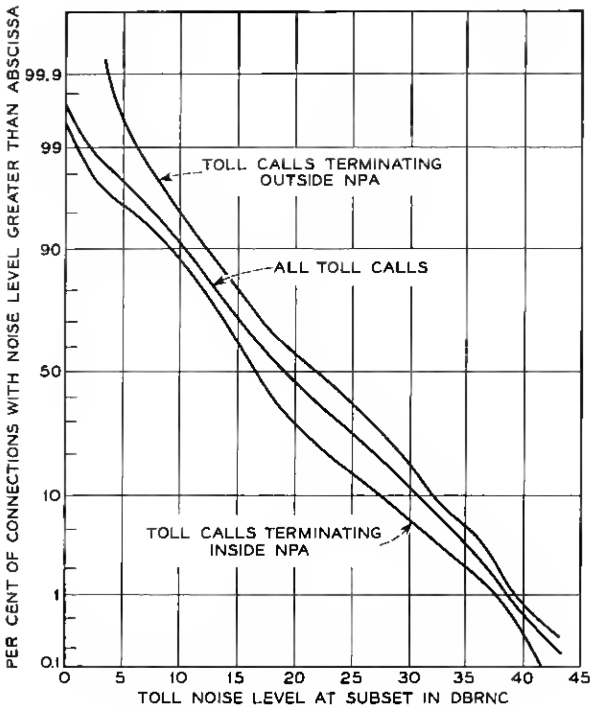

Fig. 4 — Noise level distributions.

for quantitative analysis, since two observations with coinciding distance and noise level are recorded by just one point. However, the above observations form the basis for regression analysis of noise versus distance discussed later.

Fig. 4 shows the cumulative distribution functions for noise levels on inside-NPA calls, outside-NPA calls, and all toll calls. The mean and standard deviations of these three noise distributions are given in Table II. This table also shows the precision achieved in terms of the 90 per cent confidence limits of the true mean for each of the three distributions. These confidence limits have been estimated from the sample by methods discussed in Ref. 3.

The present noise performance of the toll system in terms of the over-all objective can be estimated from Fig. 4. The "classical" over-all noise objective states that noise from all sources in a subscriber-to-subscriber connection should seldom exceed 26 dbrnc at the line terminals of the station set. Fig. 4 shows that on 23 per cent of all toll calls

TABLE II — DISTRIBUTIONS OF NOISE LEVELS ON TOLL CALLS, REFERRED TO THE SUBSET

	Mean in dbrnc	Std. Dev. in db
Inside NPA	17.4 ± 2.7	7.2
Outside NPA	23.6 ± 3.4	7.5
All toll calls	19.7 ± 2.6	7.8

this limit is exceeded even before the influence of loop noise has been considered.

A nationwide survey of transmission conditions in the switched message network, with special regard to their influence on data transmission, was undertaken in 1959.[6] In this survey, various transmission characteristics, among them message circuit noise, were measured on two classes of toll calls, short-haul calls of up to 400 miles airline distance, and long-haul calls 401–3000 miles long. The results of this survey have found wide application; a comparison with the results of the connection survey is therefore of interest. In this comparison, the distinction between calls terminating inside and outside originating NPA is nonessential. Therefore, the pooled data have been used to compute mean and standard deviation in the noise distribution on toll calls spanning 0–400 miles and 401–3000 miles, respectively. Table III gives these figures as well as those from the data survey, where the latter have been converted from dba to dbrnc. The deviations between the two sets of results are regarded as moderate in view of the different scopes and objectives of the two surveys.

Using regression analysis, the pooled data have been used further to analyze quantitatively the relation between toll noise level and distance between central offices. The independent variable x is defined as the logarithm to the base 2 of the airline distance in miles, and the dependent variable y as the toll noise level referred to the subset. The model used

TABLE III — COMPARISON OF NOISE DISTRIBUTIONS OF THE 1959 DATA SURVEY WITH THOSE OF THE 1962 CONNECTION SURVEY; NOISE LEVELS REFERRED TO THE SUBSET

	Short-Haul		Long-Haul	
	Mean, dbrnc	Std. Dev., db	Mean, dbrnc	Std. Dev., db
1959 data survey	22.0	4.7	28.9	5.5
1962 connection survey	19.1	7.4	30.3	4.5

in the analysis is that the mean noise level $E(y \mid x)$ for given distance is a linear function of x. The slope of the regression line will then be expressed in db per double distance (db/dd). An additional assumption must be made concerning the variance of y corresponding to a given value of x. The first assumption made here was that this variance is constant. The hypothesis of equality of the variances of y in the different length classes into which the data were grouped was then subjected to a statistical test. (In all regression analyses made of the connection survey data, these classes had length $x = 1$, or one double distance.) The outcome of this test (Bartlett's test) showed that the probability of the hypothesis being true was less than 0.1 per cent. On the basis of this the hypothesis of equality of the variances was rejected. The next step was to investigate the reason for this inequality of the variances. To this end a regression analysis was made with the same independent variable x as above, but with the variance of y for given values of x as the dependent variable. This analysis showed the variance to decrease with x according to the formula

$$E[\text{Var}\ (y) \mid x] = -6.6x + 80.7 \tag{1}$$

(valid for $3 \leqq x \leqq 11$); i.e., the average variance decreases at a rate of 6.6 for each doubling of the distance. The slope of the regression line (1) deviates significantly from zero; this fact is a good reason for using (1) rather than equality of the variances as an assumption in the regression analysis of y on x. Carrying through a regression analysis on this basis gave the result

$$E(y \mid x) = 2.2x + 7.9, \tag{2}$$

i.e. the average noise level increases by 2.2 db for each doubling of the distance. The hypothesis of linearity of the regression curve was tested and accepted. Therefore (1) and (2) give together in condensed form a description of the behavior of noise on toll connections as a function of the airline distance between originating and terminating central offices. A plot of these two regression lines is found in Fig. 5. The two dashed curves in this figure are confidence limits for the mean and will be discussed later.

The precision achieved in the survey is shown in Table II in terms of the 90 per cent confidence intervals for the true mean. These intervals are considerably wider than the required ± 1 db. It is therefore of interest to consider possible alternate ways of stating the precision. One reason for the poor precision achieved was the unexpectedly large variability of the mean noise levels between central offices. This is illustrated in

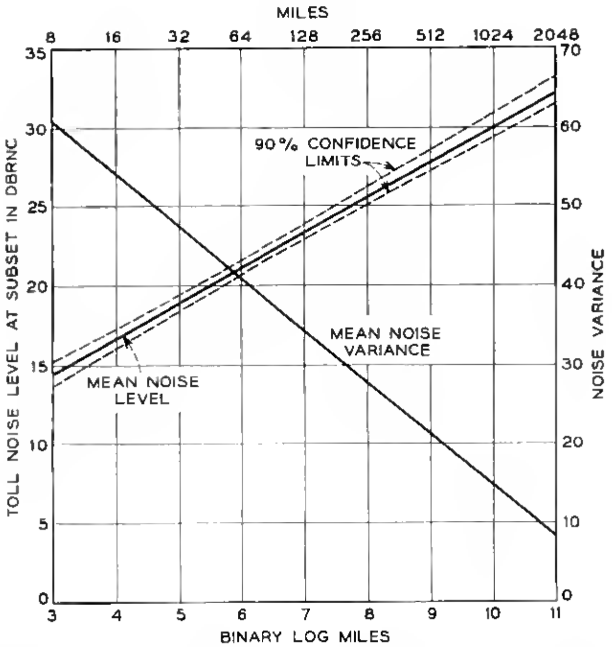

Fig. 5 — Regression lines of noise level and noise variance vs airline distance.

Table IV, which shows pooled data results for each of the 17 central offices in the sample as given by the mean of the measured noise levels, the mean of the end-office to end-office losses, and the distance in miles that corresponds to the mean of the distribution of the logarithm of the distances. One factor that contributed to this variability was the variation in calling habits and traffic patterns from one office to another. Because of the variation of noise level with distance, it seems likely that these variations should have a less pronounced effect on the precision if the latter were stated for the mean of a noise distribution on calls that are confined to a particular mileage stratum. That this is actually the case is shown in Table V, where the precision is given for the pooled data grouped into length classes, each of which is one double distance wide. Although the number of observations in each length class is considerably lower than the total, it is seen that the precision is in several cases increased, the reason being a decrease in the variability of the data.

Still another way of stating achieved precision is by way of the regression analysis. The confidence interval of the mean of y can be given

TABLE IV — CONNECTION SURVEY RESULTS: MEAN NOISE LEVEL, MEAN END-OFFICE TO END-OFFICE LOSS, AND DISTANCE CORRESPONDING TO MEAN OF DISTRIBUTION OF LOG DISTANCE

Central Office Location	Mean Noise Level at Subscriber Set, dbrnc	Mean End-Office to End-Office Loss, db	Distance Corr. to Mean of Distr. of Log Distance, Miles
Boston, Mass.	18.5	9.3	58
Brooksville, Fla.	32.5	8.3	62
Cheshire, Conn.	20.7	8.3	37
Dallas, Tex.	23.2	6.0	203
Detroit, Mich.	21.7	9.1	129
El Paso, Tex.	28.0	7.8	508
Fairfield, Conn.	18.0	7.4	28
Fort Lauderdale, Fla.	21.9	6.7	75
Hyattsville, Md.	20.9	10.3	136
Keyport, N. J.	14.1	7.3	21
Kingston, Pa.	18.2	11.5	48
Knoxville, Tenn.	25.3	6.1	121
Niagara Falls, N. Y.	24.7	6.6	33
Queens, N. Y.	16.8	8.0	36
Richmond, Va.	24.6	7.6	99
Riverside, N. J.	14.6	6.1	15
Selma, Cal.	16.8	6.2	41
Total	19.7	7.7	40

for any particular value of x. In the determination of such a confidence interval, all observations made for all x values are used. It can therefore be expected that these confidence intervals are narrower than those given in Table V. That this is true is shown by the dashed curves in Fig. 5 — the 90 per cent confidence interval has width ± 0.3 db for $x = 6.2$, and this width increases to no more than ± 0.8 db when the deviation of x from its mean value 6.2 is maximum. Looked at in this fashion, the achieved precision can certainly be regarded as satisfactory.

TABLE V — CONNECTION SURVEY PRECISION

Distance Class, Miles	Width of 90% Confidence Interval For Mean Of Noise Distribution, db
6–11	±4.0
11–23	±2.7
23–45	±3.8
45–91	±2.9
91–181	±2.4
181–362	±1.4
362–724	±1.4
724–1448	±2.1
1448–2896	±2.2
All pooled data	±2.6

As a conclusion of the discussion of noise results, it is of interest to examine present performance as expressed by noise grade of service. The over-all grade-of-service figures for all toll calls made are 97.0 per cent good or better and 0.3 per cent poor or worse. These figures indicate that the over-all noise performance of the present toll plant is quite good. However, a detailed study of the relation between grade of service and distance shows that the performance is less satisfactory on toll calls spanning large distances. This is discussed in some detail in the accompanying paper,[1] and the concept is actually used as a basic tool in the derivation of new over-all noise objectives.

5.2 *Loss*

The end-office to end-office losses are shown as a function of distance in the scatter diagrams of Figs. 6 and 7. It is apparent from these diagrams that the variation of loss with distance is only moderate. This variation is the subject of the regression analysis discussed later.

The cumulative distribution functions for end-office to end-office

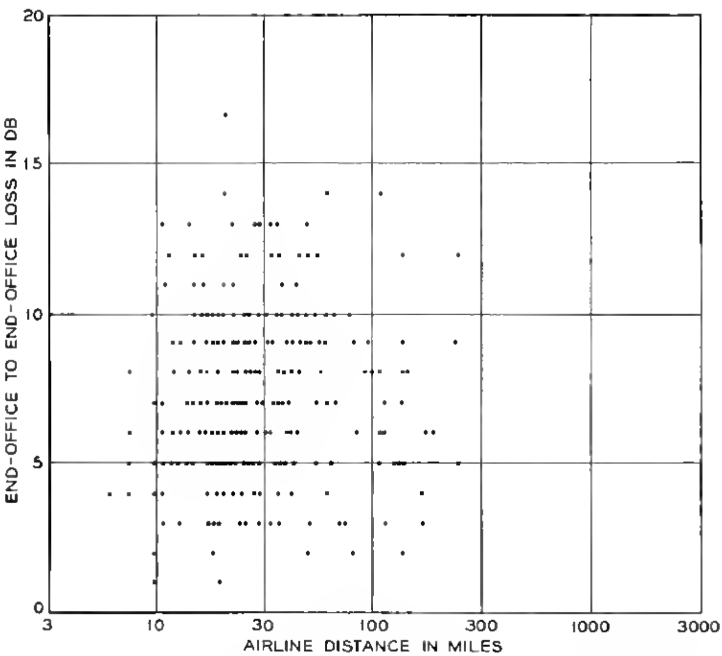

Fig. 6 — Scatter diagram of loss vs distance: toll calls terminating inside NPA.

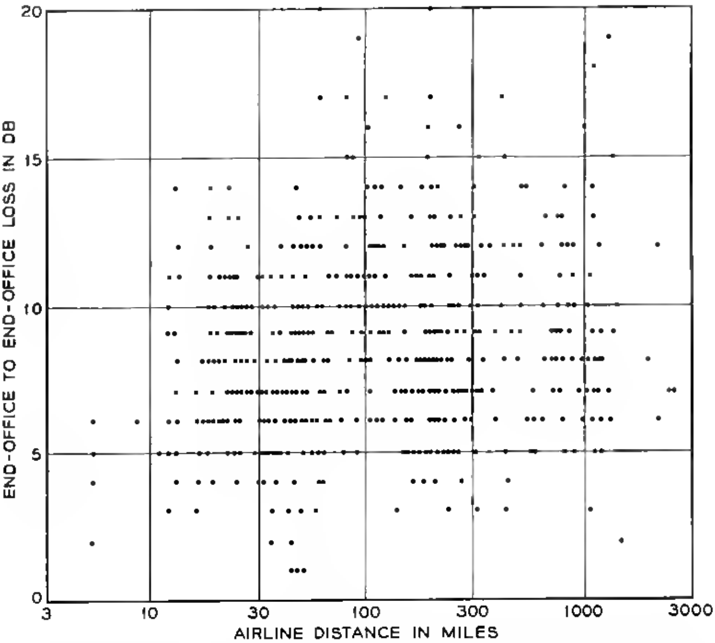

Fig. 7 — Scatter diagram of loss vs distance: toll calls terminating outside NPA.

losses on inside-NPA calls, outside-NPA calls, and all toll calls are shown in Fig. 8. The mean and standard deviations of these three loss distributions are given in Table VI.

The 90 per cent confidence intervals for the true mean loss are seen to have a width of ± 0.6 or ± 0.7. This indicates that the precision of the loss data is considerably higher than that of the noise data. The reason is that the loss distribution variances are much lower than the variances in the distributions of noise levels.

In the 1959 data survey, loss measurements were made from which the distributions of end-office to end-office losses on short-haul and

Table VI — Distributions of End-Office to End-Office Losses on Toll Calls

	Mean, db	St. Dev., db
Inside NPA	6.9 ± 0.7	2.7
Outside NPA	8.3 ± 0.6	3.1
All toll calls	7.7 ± 0.7	3.0

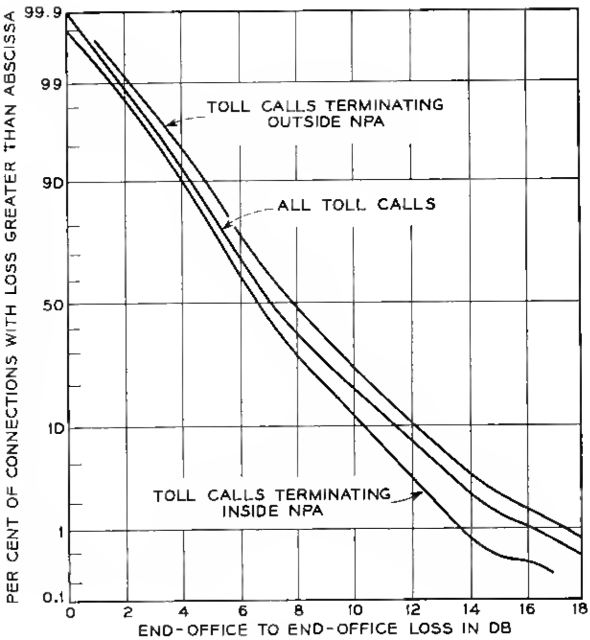

Fig. 8 — Loss distributions.

long-haul calls have been established.[7] Again, we compare these results with the corresponding distributions of the pooled data of the connection survey. The comparison is made in Table VII, which gives means and standard deviations of the corresponding distributions.

Both parameters are seen to be lower for the connection survey distributions than for those of the data survey. The difference between the means could be taken as a measure of the decrease of the average end-office to end-office losses in the toll plant between 1959 and 1962

Table VII — Comparison of Distributions of End-Office to End-Office Losses of the 1959 Data Survey with Those of the 1962 Connection Survey

	Short-Haul		Long-Haul	
	Mean, db	Std. Dev., db	Mean, db	Std. Dev., db
1959 data survey	9.5	3.7	10.9	4.0
1962 connection survey	7.8	2.7	9.3	3.5

as a result of the continuing conversion to low-loss operation. However, this *quantitative* interpretation of the data is dangerous, since the connection survey was based on probability sampling techniques, while the data survey was not.

In the regression analysis of end-office to end-office loss versus distance, the independent distance variable x was defined in the same way as for the noise analysis, while the dependent variable y was the measured loss. The pooled data were used for this analysis. Bartlett's test showed in this case that the hypothesis of equality of the variances of y corresponding to given values of x was true with probability smaller than 0.1 per cent. Therefore this hypothesis was rejected, and a regression analysis of variance versus x was performed. This analysis showed that the variance increases with x according to the formula

$$E[\mathrm{Var}(y) \mid x] = 1.5x - 0.7 \tag{3}$$

(valid for $2 \leqq x \leqq 10$); i.e., the average variance increases with 1.5 for each doubling of the distance. This slope deviates significantly from zero, so again we take this as a strong indication that the systematic variation of the variance with x according to (3) was the prime reason for the inequality of the variances. Proceeding with the regression analysis of y on x on this basis gave the result

$$E(y \mid x) = 0.6x + 4.5; \tag{4}$$

i.e., the average loss increases by 0.6 db for each doubling of the distance. The hypothesis of linearity of the regression curve was tested and accepted. It follows that (3) and (4) give, in condensed form, a description of the behavior of end-office to end-office losses on toll connections as a function of the airline distance between the offices. A plot of the two regression lines is found in Fig. 9. The two dashed curves give the 90 per cent confidence intervals for the mean of y corresponding to given values of x. The confidence interval has its minimum width of ± 0.1 db at $x = 4.7$. For low values of x the width increases to ± 0.3 db, while for high values of x the maximum width is ± 0.5 db.

It is of interest at this point to compare (1) and (3), which show that noise variance decreases and loss variance increases with distance. It can be seen from the scatter diagrams of Figs. 1 and 2 that the reason for the decrease of the noise variance with distance is the fact that a "noise floor" exists, below which no noise level occurred, and that this noise floor increases with distance, while the apparent upper limit for the noise levels is essentially constant. On the other hand, the reason for the increase of loss variance with distance is that long connections in

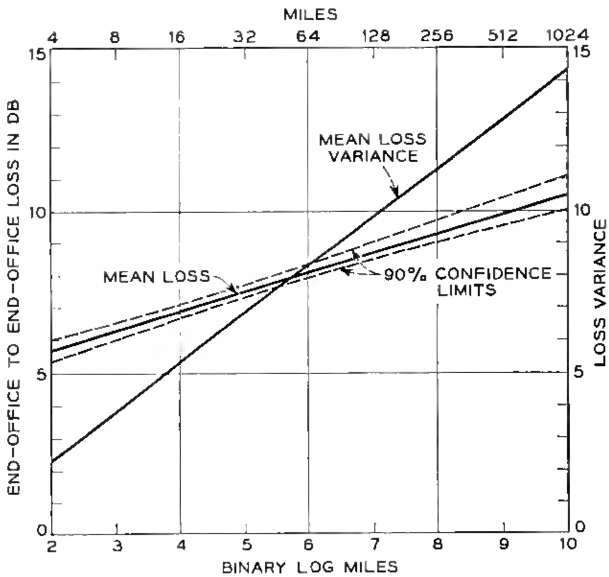

Fig. 9 — Regression lines of end-office to end-office loss and loss variance vs airline distance.

the present toll network may contain between one and seven intertoll trunks, (ITT), in tandem while for short ones the maximum possible number of ITT's is lower than seven. Over the range of distances where (1) and (3) are both valid ($3 \leqq x \leqq 10$), we find that the noise variance is always greater than the loss variance. It should be observed that these variances are not the squares of the standard deviations that appear in Tables II and VI. The latter are standard deviations of noise and loss distributions over all distances, while the former are the variances that appear when the distance is kept constant.

A nationwide survey of speech volumes, measured at the originating end of Bell System toll calls, was performed by Bell Telephone Laboratories in 1959–1961.[8] The data of that survey can be used in conjunction with our loss data to evaluate volume grade of service and thus give an insight into customer satisfaction of present toll plant loss performance. The distribution of speech volumes on toll calls, referred to the originating central office, has a mean of −16.8 VU with a standard deviation of 6.4 db. By applying volume opinion curves,[9] we find that the present distribution of losses on all toll calls gives a received volume grade of service of 87.1 per cent good or better and 1.2 per cent poor or worse.

These figures can be compared with the grade-of-service estimates of 83 per cent good and 3 per cent poor or worse that were made on the basis of a 1950 volume survey.[10] The comparison indicates a substantial improvement in satisfaction of received volumes over the time period 1950–1962.

5.3 *Distance*

The airline distance between originating and terminating central offices is known for each call in the sample. The distributions of these distances for inside-NPA, outside-NPA and all toll calls, respectively, are shown in Fig. 10. It is seen from this figure that 50 per cent of all toll calls are shorter than 30 miles, and that only 10 per cent are longer than 250 miles. The distance scale used in Fig. 10 is logarithmic, and in this way the distributions plotted have reasonably low skewness. Had a linear scale been used instead, the distributions would have been ex-

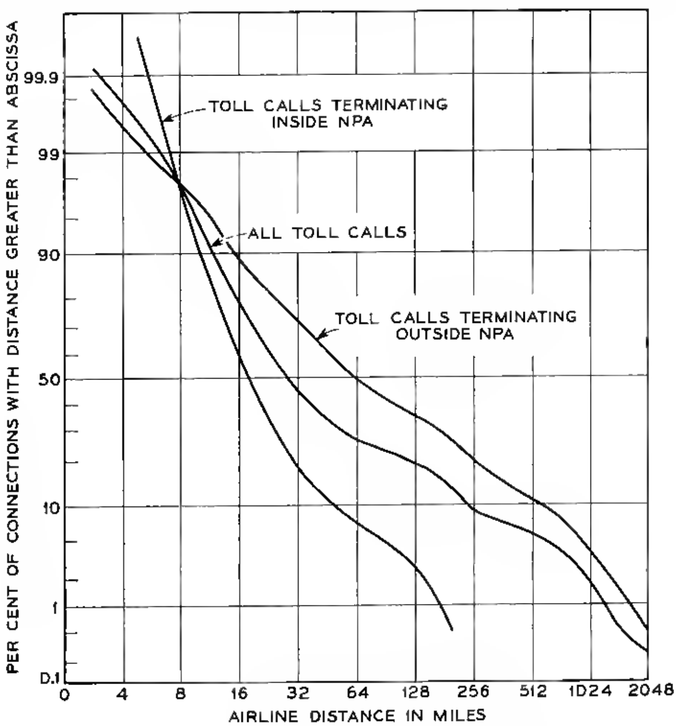

Fig. 10.— Distributions of distances spanned by toll calls.

TABLE VIII — DDD CALLS EXPRESSED AS A PERCENTAGE OF ALL TOLL CALLS IN DIFFERENT DISTANT CLASSES

Distance Class, Miles	Proportion of Toll Calls Direct-Dialed by Customers
3–6	73
6–11	84
11–23	66
23–45	58
45–91	45
91–181	33
181–362	38
362–724	27
724–1448	17
1448–2896	20
All toll calls	55

tremely skew, and a plot would reveal very little about their true character.

The proportions of toll calls that are direct-dialed by customers (DDD calls) have been evaluated from the connection survey data. Table VIII shows the results of these evaluations as a function of distance. It can be seen that although an average of 55 per cent of all toll calls (as defined in Section II) are DDD calls, this percentage is not constant with distance. Thus, about 80 per cent of the short-haul toll calls are direct-dialed by customers, and this percentage decreases with distance to a value of about 20 in the longest category.

Some questions related to the routing of toll calls in the present Bell System toll network can be answered on the basis of connection survey data. Two examples are: (*i*) the average number of intertoll trunks and (*ii*) the relation between circuit length and airline distance, both given as a function of the distance spanned by the toll connection. Further studies would, however, be required to answer any of these or similar questions.

VI. CONCLUDING REMARKS

The feasibility of performing a statistically sound sample survey of the very complex Bell System toll plant has been satisfactorily shown by the survey described in this article. The prime importance of the survey lies in the information it gives about noise and loss performance of the present toll plant. However, a significant and very important part of the result is the experience that has been gained in carrying through a systemwide sample survey. Specifically, it should be pointed out that the two-stage sampling plan used is extremely well suited for surveys of

transmitted and received speech volumes, as well as noise, loss, and composition of loops, of facilities and of trunks. The acquiring of data of these types is vital in the present work of building a statistical model of the Bell System plant.

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